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(54) Title: QAM SYSTEM IN WHICH THE CONSTELLATION IS MODIFIED IN ACCORDANCE WITH CHANNEL QUALITY
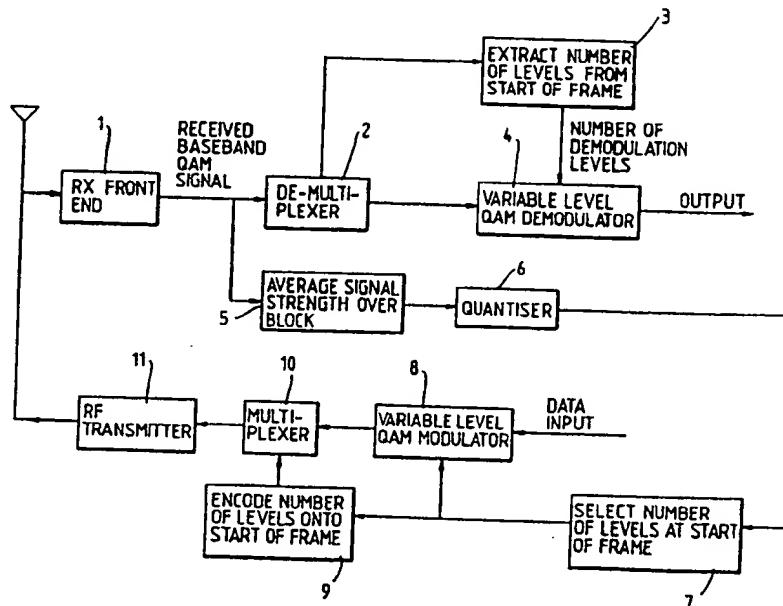
(57) Abstract

A radio system is so designed as to allow each of a pair of transceivers to assess the quality of the link, and to modify the signal constellation accordingly. Each transceiver monitors the quality of the channel by assessing the strength of the received signal, or the bit error rate, or both. The system is specifically adapted to time division duplex (TDD) transmission over fast fading channel. In each block of data, the first bit is a QPSK (4QAM) signal, which indicates which constellation is to be used.

QAM system in which the constellation is modified in accordance with channel quality.

The present invention relates to a radio system, and in particular, though not exclusively, to a radio system for mobile radio using Quadrature Amplitude Modulation (QAM) as a modulation scheme.

5   QAM transmissions over Rayleigh fading mobile radio channels are subjected to error bursts due to deep fades, even when the channel signal-to-noise ratio (SNR) is high.   This leads to the notion of varying the number of modulation levels according to the integrity of the

10   channel, so that when the transmissions are not subject to fading the number of modulations levels could be increased by increasing the number of QAM constellation points, and when fading occurs the number of constellation points could be reduced to a value which

15   provides an acceptable bit error rate (BER).   If the required BER and switch levels are specified accordingly, variable data throughput results. Alternatively, if throughput is kept reasonably constant a variable BER is obtained.

20   One approach is to have a variable rate system with duplex transmission and some method of informing the transmitter at one end of the radio link of the quality of the link as perceived by the receiver at the other end of the link.   The transmitter can then respond by

25   changing the number of QAM levels according to the quality criteria adopted.   Successful variable rate transmission requires that the fast fading channel changes slowly compared to a number of symbol periods. If this condition is not met, then the frequent

30   transmission of quality control information will significantly increase the bandwidth requirements of the system.

The present invention seeks to provide a radio system in which transmissions are adapted to transmission

35   conditions.

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According to a first aspect the invention provides a radio system comprising a pair of stations at least one of which has a radio transceiver having:

a radio receiver for receiving signals from the
5   other station;

means for assessing the received radio signals;

means for selecting a transmission modulation state on the basis of the assessment of the received signals;

a radio transmitter for transmitting signals to the
10   other station using a modulation scheme having a plurality of modulation states;

means for adjusting the transmitting state of the radio transmitter to be the selected modulation state; and

15   signalling means for including in the signals to be transmitted to the other station an indication of the selected modulation state.

According to a second aspect the invention provides a radio transceiver for the transmission of digital
20   signals characterised in that the number of binary digits encoded onto each symbol for transmission is varied according to measured received signal strength, the measured bit error rate (BER) or some combination of these.

25   According to a third aspect the invention provides a radio transceiver characterised in that the received signal strength is averaged over a predetermined time period and the number of bits/symbols to be used in forthcoming transmissions is determined according to this
30   average.

According to a fourth aspect the invention provides a radio transceiver characterised in that errors in received decoded digital signals are identified using an error detection system, and the number of bits/symbol to
35   be used in forthcoming transmissions is based on the number and distribution of the errors detected.

According to a fifth aspect the invention provides a radio system wherein the radio communication is bi-directional but instantaneously uni-directional, the data being placed in packets or blocks and the initial symbols in each block being reserved for signalling the number of bits/symbol to be used in the block.

According to a sixth aspect the invention provides a a mobile radio system for operation over radio channels with fast fading wherein the number of modulation levels is varied at a rate commensurate with the fast fading.

According to a seventh aspect the invention provides a radio transceiver comprising:

a radio receiver for receiving radio signals;

means for assessing the received radio signals;

means for selecting a transmission modulation state on the basis of the assessment of the received signals;

a radio transmitter for transmitting signals using a modulation scheme having a plurality of modulation states;

means for adjusting the transmitting state of the radio transmitter to be the selected modulation state; and

signalling means for including in the signals to be transmitted an indication of the selected modulation state.

To reduce the problem of fast fading the data rate could be increased, allowing the transmission of more symbols before the channel changes significantly. The slower the mobile travels, the slower the fading rate and the lower the signalling rate required for adapting to the channel.

Varying the number of QAM levels in response to fading conditions can result in a variable bit rate, which although nearly constant over long periods, could instantaneously vary by four times the average rate. Consequently, it is appropriate to consider strategies

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for using adaptive or multi-level QAM, while transmitting data rather than speech. Data transmissions often have the virtue that a variable throughput, and relatively large delays, can be tolerated provided the BER is sufficiently low. For fully successful computer file transfer the BER must be zero.

Preferred embodiments of the invention will now be described by way of example, and with reference to the accompanying drawings, wherein:

Figure 1 illustrates schematically a framing structure for use with a variable level QAM scheme;

Figure 2 illustrates a series of QAM constellations for use in a variable level QAM scheme;

Figure 3 illustrates a radio transceiver of a preferred embodiment of the invention;

Figure 4 shows a graph illustrating the variation of bits/symbol with fading level;

Figure 5 shows a graph illustrating the variation of bits/symbol with fading level;

Figure 6 shows a graph illustrating comparative BER for fixed and variable modulation schemes;

Figure 7 illustrates schematically a radio transceiver according to a preferred embodiment of the invention;

Figure 8 shows a graph illustrating variation of bits/symbol with fading level; and

Figure 9 shows a graph illustrating performance of a DECT-like system.

The simplest duplex arrangement for variable rate modem operation is Time Division Duplex (TDD), where both Base Station (BS) and Mobile Station (MS) transmit over the same channel, but at different times. In this case both the BS and the MS experience similar channel fading conditions as their transmissions are typically half a TDD frame apart. The transmission received by the MS is used to estimate the channel integrity which then

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dictates the number of QAM levels to be used by the MS
transmitter. Similarly, the transmission received by the
BS enables the number of QAM levels to be used in the
subsequent BS transmission to be determined. Both the BS
5   and MS should inform the other of the number of QAM
levels used by their transmitters and this information
should not be corrupted by the channel, in order for the
QAM demodulations to be properly performed. In
simulations data was divided into blocks, or packets that
10   occupy a time slot, and the first few symbols in each
block are reserved for signalling. The optimum size of
the block is related to the mobile speed as the channel
should not change significantly over the block duration.
Blocks of 100 symbols were used for transmissions at
15   512kSym/s, a mobile speed of 30mph and a carrier
frequency of 1.9GHz. At the start of each block a signal
was sent representing the number of levels to be used in
the block. This was encoded onto two symbols of a 4-level
QAM, i.e., QPSK system, and each of these two symbols was
20   transmitted three times. Majority voting was performed at
the receiver in order to establish the number of QAM
levels to demodulate in the current block. With larger
block sizes, higher integrity codes can be used on the
information containing the number of levels without
25   significantly reducing the throughput. Figure 1 shows
the TDD framing arrangement for adaptive QAM
transmissions using one carrier per channel. If N
channels per carrier are used the QAM symbols shown in
the Figure are transmitted N times faster, but the time
30   over which the fading channel must remain essentially
unchanged is the same, i.e. on the basis that the cells
are suffi ently small for flat Rayleigh fading to apply.
The QAM constellation changes as the number of levels is
varied. Conventional QAM having a square constellation
35   are not used because of the difficulties with carrier
recovery in a fading environment. Instead Star QAM having

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a circular star constellation is used, in conjunction
with differential coding, as this has proved to be more
successful in previous simulations. The principle of Star
QAM is to provide a constellation upon which differential
5   coding can be efficiently overlaid. Both differential
phase and amplitude coding is used. With 16-level Star
QAM three of the four bits which constitute a symbol are
differentially Gray encoded onto the phase, and the
remaining bit is differentially encoded onto the
10   amplitude of the phasor. This simplifies the receiver as
AGC and carrier recovery are no longer required.
Simulations have shown that BER performance is
substantially improved over the square constellation
whose receiver has the difficulty of accurately
15   estimating the absolute signal phase and amplitude when
both are varied randomly by the modulator and both are
also influenced by the rapidly changing Rayleigh fading
propagation channel. Star QAM has the further advantage
over Square QAM that each of the four bits constituting a
20   symbol has a similar BER, making speech and data mapping
straightforward. This is not the case for Square QAM
where half of the bits mapped onto a 16-level grey-coded
constellation have a significantly higher BER than the
other half. In simulations constellations from 1 bit/sym
25   (BPSK) through to 6 bits/sym were used. Provided the
receiver noise is sufficiently low, and implementation
complexity is not an inhibiting factor, more than 6
bits/sym can be used. As the number of bits/sym is
increased the number of amplitude rings and the number of
30   phase points is alternately doubled. Starting with BPSK,
for 2 bits/sym the number of phase points is doubled to
get QPSK. For 3 bits/sym the number of amplitude levels
is doubled to get 2-level QPSK. For 4 bits/sym the number
of phase points is doubled to get to the 16-level Star
35   constellation, and so on until with 6 bits/sym 4 rings
having 16 points per ring. The constellations for

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2-level to 64-level Star QAM are shown in Figure 2. The
actual distances between the rings, and the sizes of the
rings are not drawn to scale.   Each constellation has the
same average energy, and the radii of the rings in the 8

5   and 16-level constellations are in the ratio of
three-to-one.

The differential encoding is correctly initiated by
using the convention that the point before the first data
symbol is sent on the innermost amplitude ring at 0

10   degrees, and we then calculate our differentially encoded
data from this phasor.

The block diagram of a transceiver is shown in
Figure 3. After recovering the baseband signal by
receiver (RX) front end 1, demultiplexing is performed by

15   de-multiplexer 2 to separate the QPSK and Star QAM
signals. QPSK demodulation is performed by QPSK
demodulator 3 to obtain the number of QAM levels to be
used in the QAM demodulation. This is followed by QAM
demodulation by QAM demodulator 4 to yield the recovered

20   data. The average magnitude of the baseband signal level
over a block is measured by average monitoring unit 5 to
provide an indication of the short-term path loss of the
radio channel. If this average is very low the mobile is
either in a deep fade or at the edge of the cell. In

25   either case it is more appropriate for it to transmit
using relatively few QAM levels. Conversely, if the
average is high the channel is relatively good, enabling
more QAM levels to be used in its next transmission.   The
average over a block is computed using an exponential

30   smoothing process which gave more weight to signal level
towards the end of the block.   This average is quantised
by quantiser 6, each quantised output signifying a
particular number of QAM levels to be used in the
forthcoming transmission.

35   In the transmitter part of the transceiver of figure
3, the output of quantiser 6 is fed to a level selection

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unit 7.   The level selection unit 7 controls a variable
level QAM modulator 8 to modulate a data input stream.
The level selection unit 7 also controls a level encoding
unit 9 which encode the selected QAM level into the start
5   of frame.   Outputs from QAM modulator 8 and level
encoding unit 9 are fed to a multiplexer 10, and
multiplexer 10 feeds an RF transmitter unit 11.
       The baseband signal in Figure 3 is related to the
received signal strength indicator (RSSI) at RF. The
10   system would function identically if the RF RSSI, instead
of the baseband RSSI indicator, was averaged over a
block. For ease of nomenclature, this method of switching
the QAM levels based on the baseband signals is called
baseband RSSI switching, or more simply, RSSI switching.
15   Two criteria are used for these switching levels,
i.e. the levels generated by the quantiser in Figure 3.
One is to select the switching levels to achieve a
specified BER, resulting in a variable data throughput.
A simulation was conducted where graphs of BER as a
20   function of SNR at the input to the QAM demodulator were
found for the Star QAM modem having 2^n; n=1, 2, ...6 fixed
levels. In this simulation a Gaussian channel was used,
as over any short period of time when we do our switching
the channel is essentially a constant level plus Gaussian
25   noise. A straight line corresponding to the BER of
interest was then drawn and where this horizontal line
intersected the curves identified the switching
thresholds. The SNR was therefore quantised, with the
quantisation zones corresponding to different number of
30   QAM levels in the adaptive modem. Some hysteresis was
built into the switching levels to prevent continual
level changing. The baseband signals in Figure 3 are
contaminated by noise, which the averaging circuit
considerably reduces prior to QAM level selection at the
35   end of the block. To ensure that the quantiser output
levels correspond to the required SNR values, the average

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value of the QAM symbols (found at the end of the block)
was appropriately scaled by the known receiver noise
prior to quantisation. Figure 4 shows an arbitrary
segment of the signal applied to the QAM demodulator, and
5   the number of bits/sym selected during this period. The
figure was produced from a simulation at 30dB with other
parameters as stated previously. Because of the
relatively high SNR, much of the time the modem attained
its maximum 6 bits/sym.

10   The second criteria for choosing the switching
thresholds achieved a constant average bit rate whilst
accepting a variable BER. Here the thresholds derived
above were used for the constant BER system and these
were multiplied by the same number at the start of each
15   block.   This number was derived from the baseband signal
averaged over a number of fades. This merely involved
adding an extra averaging circuit with the averaging
window increased over that used to average over a block
in Figure 3, so that it covered many blocks.   Therefore
20   as the average signal level rose, for example when moving
closer to the base station, the switching thresholds
increased accordingly maintaining a near constant average
throughput, but variable BER.   The average bits/sym could
be set to any level within the maximum number of bits/sym
25   by changing the scaling factor associated with the long
term average input. Where the average bit rate was the
same for both selection criteria, they both gave
identical BERs, and can be viewed as equivalent systems.
Figure 5 shows switching profiles for this constant
30   throughput scheme over the same section of fading channel
as for the previous profile. Again an SNR of 30dB is
used.   Here there is considerably more level changing in
an effort to keep the average to 4 bits/sym. If a lower
SNR had been chosen for both graphs then they would
35   appear more similar.

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Channel coding can be added to both the above
systems, in our case in the form of systematic BCH codes.
The data was encoded and interleaved over 15,600 bits
before being passed to the input of the QAM modulator in
5   Figure 3.   At the output of the demodulator
de-interleaving was performed in an attempt to randomize
the bursty channel errors before channel decoding takes
place.   The variable QAM schemes have the advantage over
the fixed QAM scheme that errors occurred in smaller
10   blocks because of the use of fewer QAM levels in poor
channels. This allows the channel codecs to perform more
efficiently.   The performance of the RSSI switching
system with channel coding is considered below.

The performance of the RSSI switched variable level
15   Star QAM system compared to a fixed 16-level (4 bits/sym)
Star QAM system is shown in Figure 6.   The adaptive QAM
system has had its switching thresholds adjusted to also
give 4 bits/sym.   The necessary signalling information of
the number of QAM levels used has been taken into account
20   in calculating this throughput. The simulation was
performed for a propagation frequency of 1.9GHz, a
vehicular speed of 30mph, and a transmitted symbol rate
of 512KSym/sec, providing a bit rate of 2048Kbits/sec on
average. The propagation environment has been assumed to
25   be microcellular so that ISI is insignificant. It can be
seen that there is a significant improvement in the
performance of the adaptive over the fixed modem at all
SNRs, and that this improvement is enhanced with
increasing SNR.

30   Rather than switching the QAM levels on RSSI this
switching can be done on the command of a channel codec,
in this case a systematic BCH codec. Figure 7 shows a
simplified block diagram of the BER switching
transceiver.   In figure 7, parts in common with the
35   transceiver of figure 3 have like numerals.   The
transceiver of figure 7 differs from the transceiver of

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figure 3 in that the receiver part the output of
demodulator 4 is provided to a BCH decoder 21. The BCH
decoder 21 provides a "no errors" output to decision unit
22, and an "errors detected" output to decision unit 23.

5   Decision units 22, 23 control level selection unit 7
appropriately. Further, in the transmitter part of the
transceiver of figure 7 the input data stream passes
through channel coder 24 before being supplied to QAM
modulator 8.

10   In order to obtain an estimate of the channel during
each received data packet, a BCH(63,57,1) code is
overlaid onto the last 57 bits of input data in each
block. The input data may already have been channel coded
and interleaved using the same system as described in the

15   previous section, the additional coding is overlaid onto
whatever data was present. This codec was generally
ineffective at correcting errors as it was overwhelmed by
the non-interleaved errors in a typical error burst, but
it informed the receiver that channel conditions were

20   poor. Such a coding system involved little overhead as it
was only applied to the final 57 bits in a block which
contained an average of 400 bits. The coded data was
applied to the adaptive QAM modulator and the modulated
output was up-converted and transmitted. The QAM

25   demodulation was performed using the number of QAM levels
extracted from the header, as described in the section on
the RSSI switched QAM system. Most of the data was passed
to the output where it might be subjected to
de-interleaving and channel decoding. However, the final

30   63 bits of the recovered bit stream were passed through
the BCH(6 ,57,1) codec 21 before proceeding to the
output. If no errors were detected by this BCH codec then
the number of QAM levels used in the next block was
doubled, otherwise they were halved. Switching profiles

35   for the same section of channel as used in Figures 4 and
5 are shown in Figure 8. Again a channel SNR of 30dB was

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used. This figure shows the BER switched system had a
similar level switching profile to the variable
throughput RSSI system, as might be expected. The lack of
hysteresis on level switching is evident but it does not
5   cause any additional signalling overhead, nor
significantly alter the BER.

The digital European cordless telecommunications
(DECT) system uses TDD, supporting 12 channels per
carrier. The 12 down-link and 12 up-link channels
10   constitute a 24 slot frame lasting 10ms. Each time-slot
containing a packet has a duration of 0.417ms. The data
in the packet consists of 320 bits which are transmitted
at 1152kSym/s. In a simulation each bit was replaced by a
QAM symbol to increase system capacity. The header
15   informed the receiver of the number of constellation
points. The RSSI switching system was employed. Figure
9 shows the variation of BER as a function of channel SNR
for this DECT-like system for MSs travelling at different
speeds. No co-channel interference was present. The
20   DECT framing meant that the transmission and reception
were separated by 12 slots or 5ms, and consequently the
channel could occasionally experience considerable
changes between transmission and reception of data and
therefore generate an inappropriate number of levels.
25   When the MS travelled faster the BER deteriorated and
when the mobile's speed was 20mph the adaptive and the
fixed four-level QAM had similar performances. However,
an order of magnitude improvement in BER was achieved for
a given channel SNR in excess of 20dB when the mobile's
30   speed was decreased from 20 to 5mph. This was due to the
slower fading rate making the channel estimation more
accurate. An adaptive Star QAM modem for transmission of
data over Rayleigh fading channels using a variable
number of modulation levels has been proposed. Criteria
35   for deciding how to vary the number of modulation levels
to give a required performance characteristic are

presented. The adaptive QAM modem can be arranged to
provide a near constant BER over a wide range of channel
SNRs, although the bit rate may vary considerably. This
type of performance is suitable for data services that
5   can tolerate some delay. In general, the adaptive modem
provides the flexibility to vary both the BER and the bit
rate in a prescribed manner to suit a particular
application. The adaptive modems have a better
performance than the fixed modems both with and without
10 co-channel interference.

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CLAIMS

1.   A radio system comprising a pair of stations at
least one of which has a radio transceiver having:
     a radio receiver for receiving signals from the
5   other station;
          means for assessing the received radio signals;
          means for selecting a transmission modulation state
on the basis of the assessment of the received signals;
          a radio transmitter for transmitting signals to the
10   other station using a modulation scheme having a
plurality of modulation states;
          means for adjusting the transmitting state of the
radio transmitter to be the selected modulation state;
and
15   signalling means for including in the signals to be
transmitted to the other station an indication of the
selected modulation state.

2.   A radio system as claimed in claim 1 wherein the
signalling means has means for adjusting the modulation
20   state of the radio transmitter to transmit the indication
of the selected modulation state in a predetermined one
of the modulation states.

3.   A radio system as claimed in claim 1 or 2 wherein
the radio system operates using time division duplex
25   operation.

4.   A radio system as claimed in claim 1, 2 or 3 wherein
the modulation scheme of the transmitter is quadrature
amplitude modulation.

· 5.   A radio system as claimed in any one of claims 1 to
30   4 wherein the means for assessing the received radio

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signals assess either or both the received signal
strength or bit error rate of those signals.

6.   A radio system as claimed in any preceding claim
wherein each station has a radio transceiver as defined
5   in any of the preceding claims.

7.   A radio transceiver for the transmission of digital
signals characterised in that the number of binary digits
encoded onto each symbol for transmission is varied
according to measured received signal strength, the
10   measured bit error rate (BER) or some combination of
these.

8.   A radio transceiver characterised in that the
received signal strength is averaged over a predetermined
time period and the number of bits/symbols to be used in
15   forthcoming transmissions is determined according to this
average.

9.   A radio transceiver characterised in that errors in
received decoded digital signals are identified using an
error detection system, and the number of bits/symbol to
20   be used in forthcoming transmissions is based on the
number and distribution of the errors detected.

10.   A radio system wherein the radio communication is
bi-directional but instantaneously uni-directional, the
data being placed in packets or blocks and the initial
25   symbols in each block being reserved for signalling the
number of bits/symbol to be used in the block.

11.   A mobile radio system for operation over radio
channels with fast fading wherein the number of
modulation levels is varied at a rate commensurate with
30   the fast fading.

12. A radio transceiver comprising:

a radio receiver for receiving radio signals;

means for assessing the received radio signals;

means for selecting a transmission modulation state

5   on the basis of the assessment of the received signals;

a radio transmitter for transmitting signals using a

modulation scheme having a plurality of modulation

states;

means for adjusting the transmitting state of the

10   radio transmitter to be the selected modulation state;

and

signalling means for including in the signals to be

transmitted an indication of the selected modulation

state.

Fig.1.

THE FRAMING STRUCTURE USED IN THE VARIABLE LEVEL SCHEME

MS RECEIVES ────────── MS TRANSMITS ──────

| QAM SYMBOLS | QAM SYMBOLS | ──── TDD FRAME

QAM DEMOD.
AND NO. OF QAM
LEVELS TO BE USED
IN TRANSMISSIONS
DETERMINED.

QPSK SYM. OF NO.
OF LEVELS USED IN
DATA TRANSMISSION

MAJORITY VOTING
APPLIED TO QPSK
DATA TO FIND NO.
OF QAM LEVELS FOR
DEMODULATION

| QAM SYMBOLS | QAM SYMBOLS |
──── BS RECEIVES ──── BS TRANSMITS ────

PROPAGATION
DELAY

THE FADING
CHARACTERISTICS
REQUIRED TO BE
APPROXIMATELY
CONSTANT.

Fig.6.

BER COMPARISON OF VARIABLE AND FIXED SYSTEM

── FIXED ── RSSI SWITCH
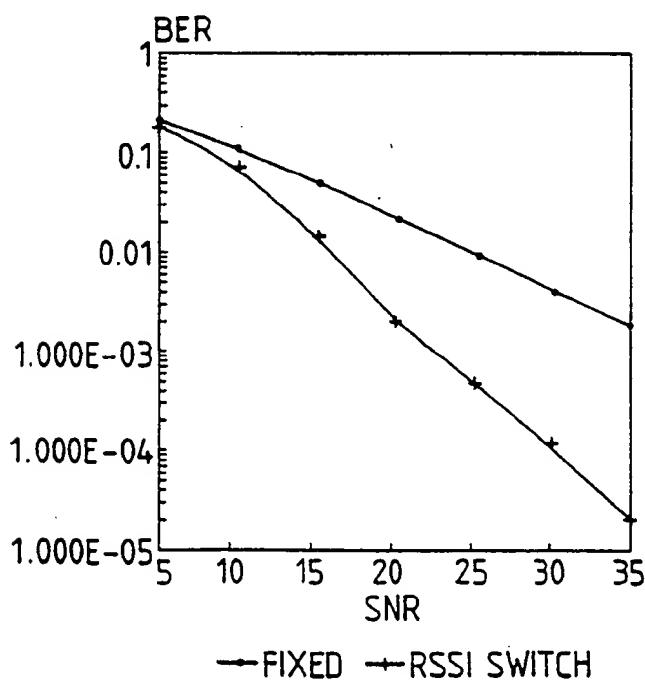
Fig. 2.

SOME QAM CONSTELLATIONS USED IN THE VARIABLE LEVEL SCHEME

BPSK

QPSK

STAR QAM

2-LEVEL QPSK

5 BITS/SYM
32-LEVEL STAR QAM

6 BITS/SYM
64-LEVEL
STAR QAM

Fig. 3.
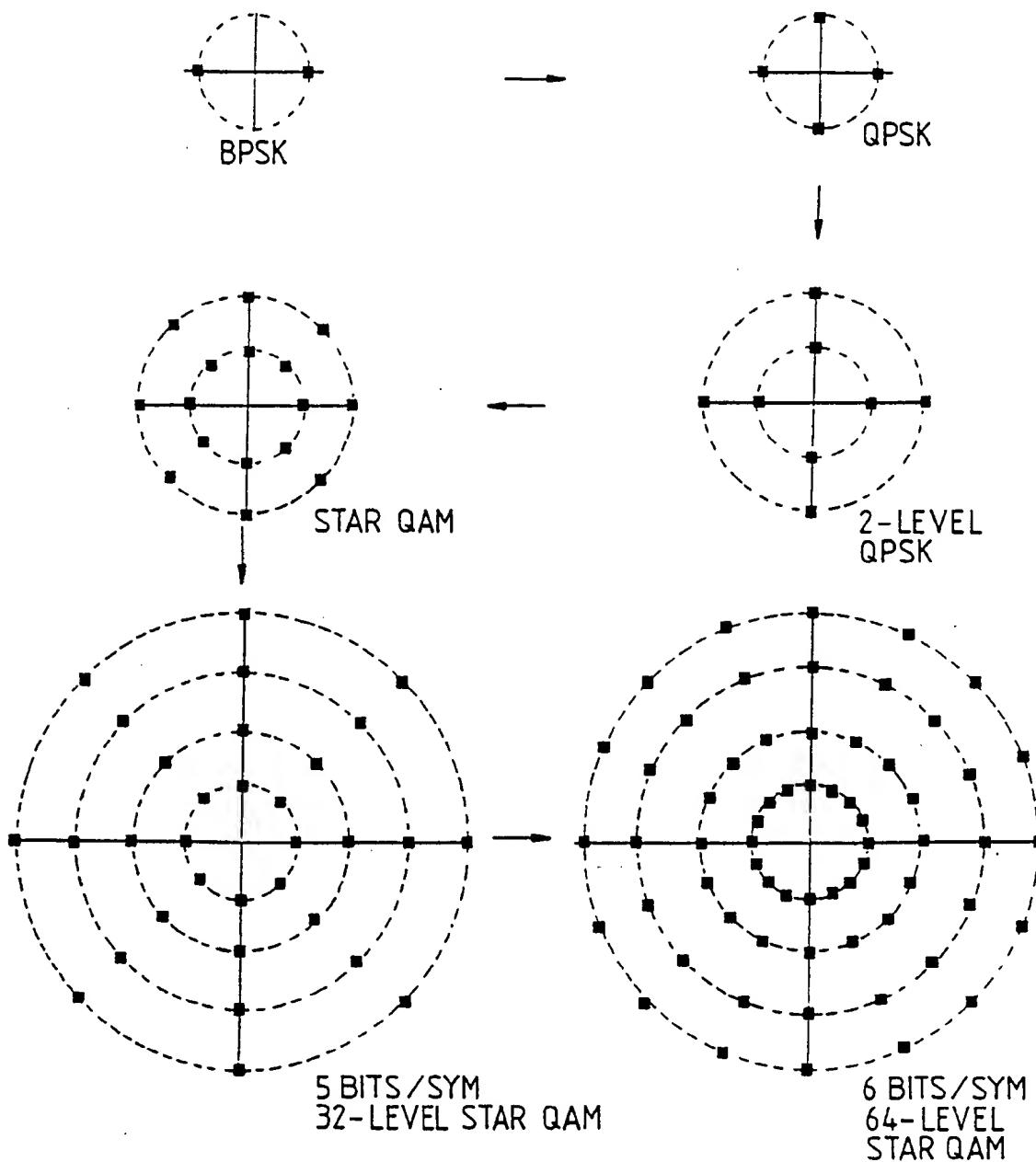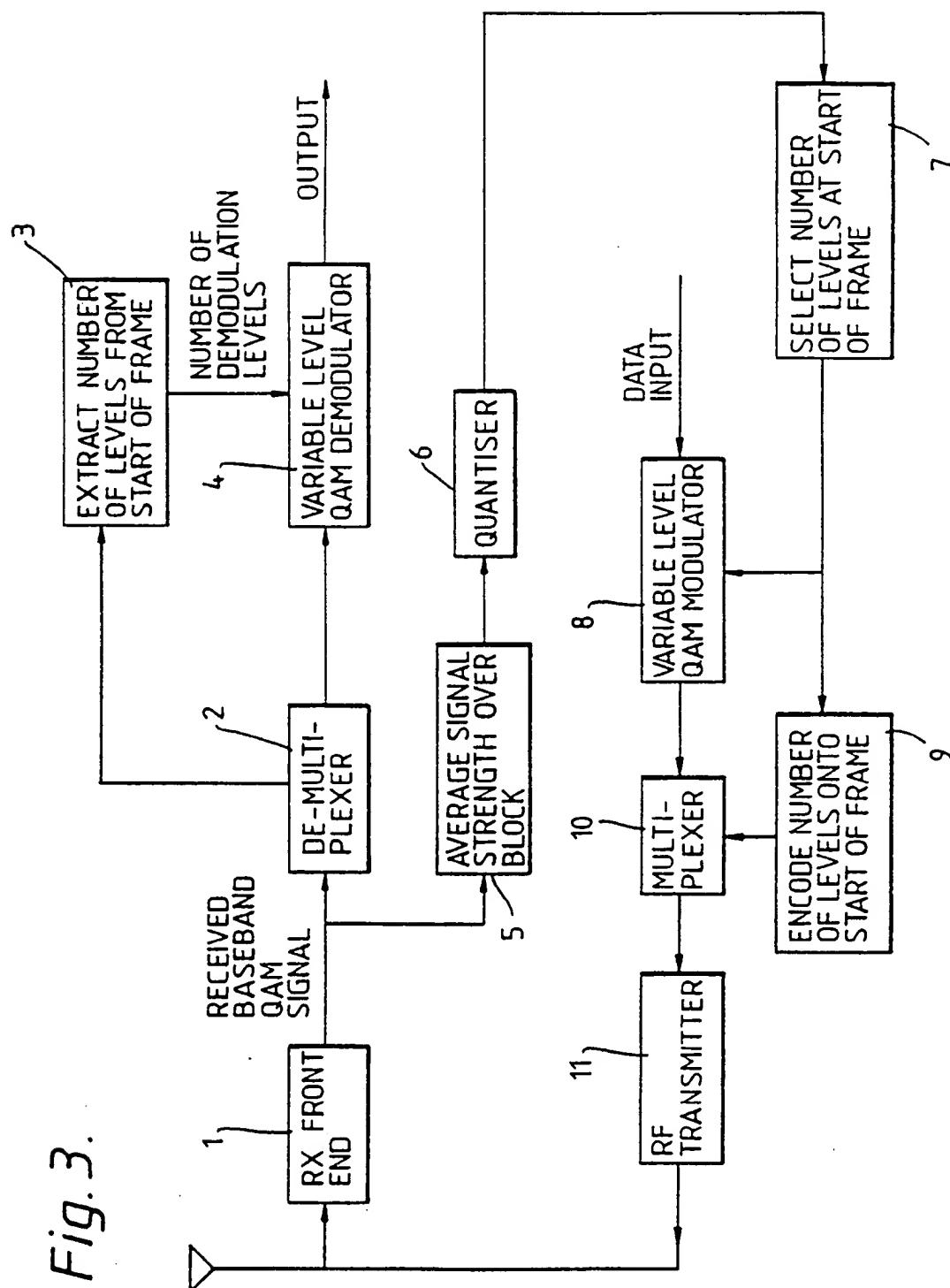
Fig.4.

EXAMPLE OF RSSI SWITCHING FOR VARIABLE BIT RATE
### RSSI SWITCHING SYSTEM
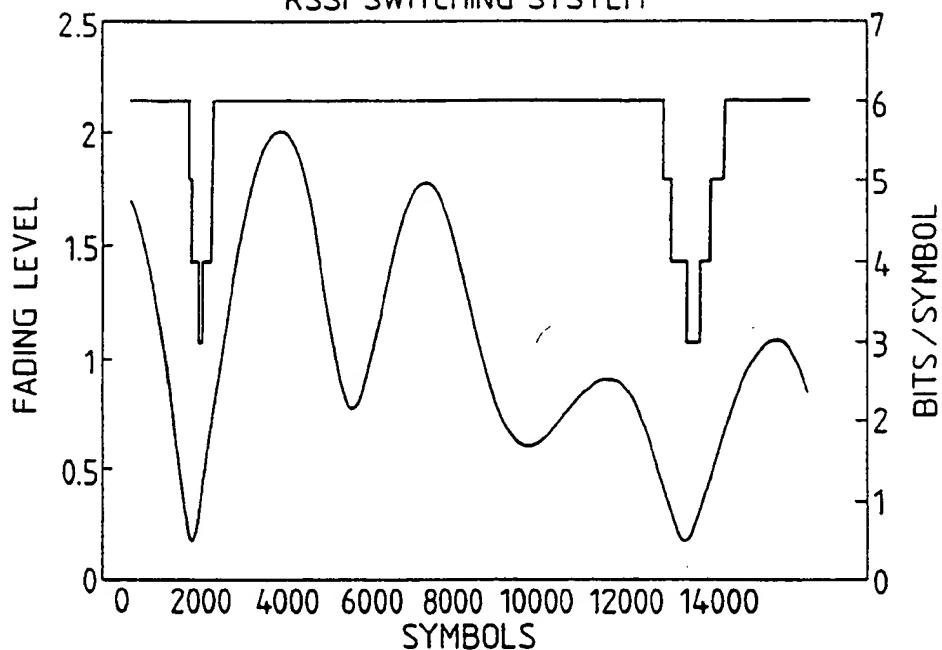
Fig.5.

EXAMPLE OF RSSI SWITCHING FOR CONSTANT BIT RATE
RSSI SWITCHING SYSTEM

Fig.7.
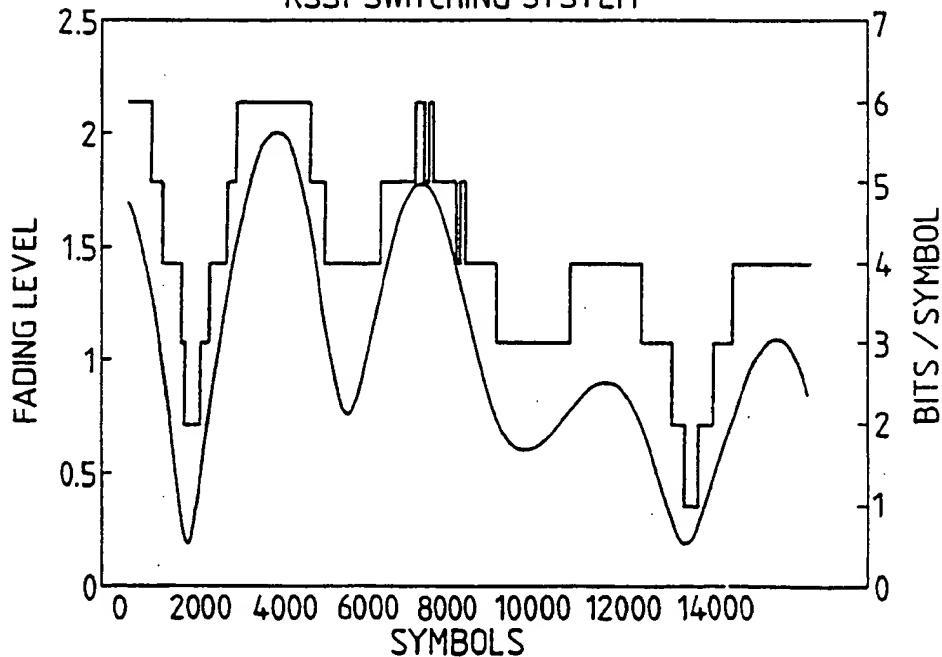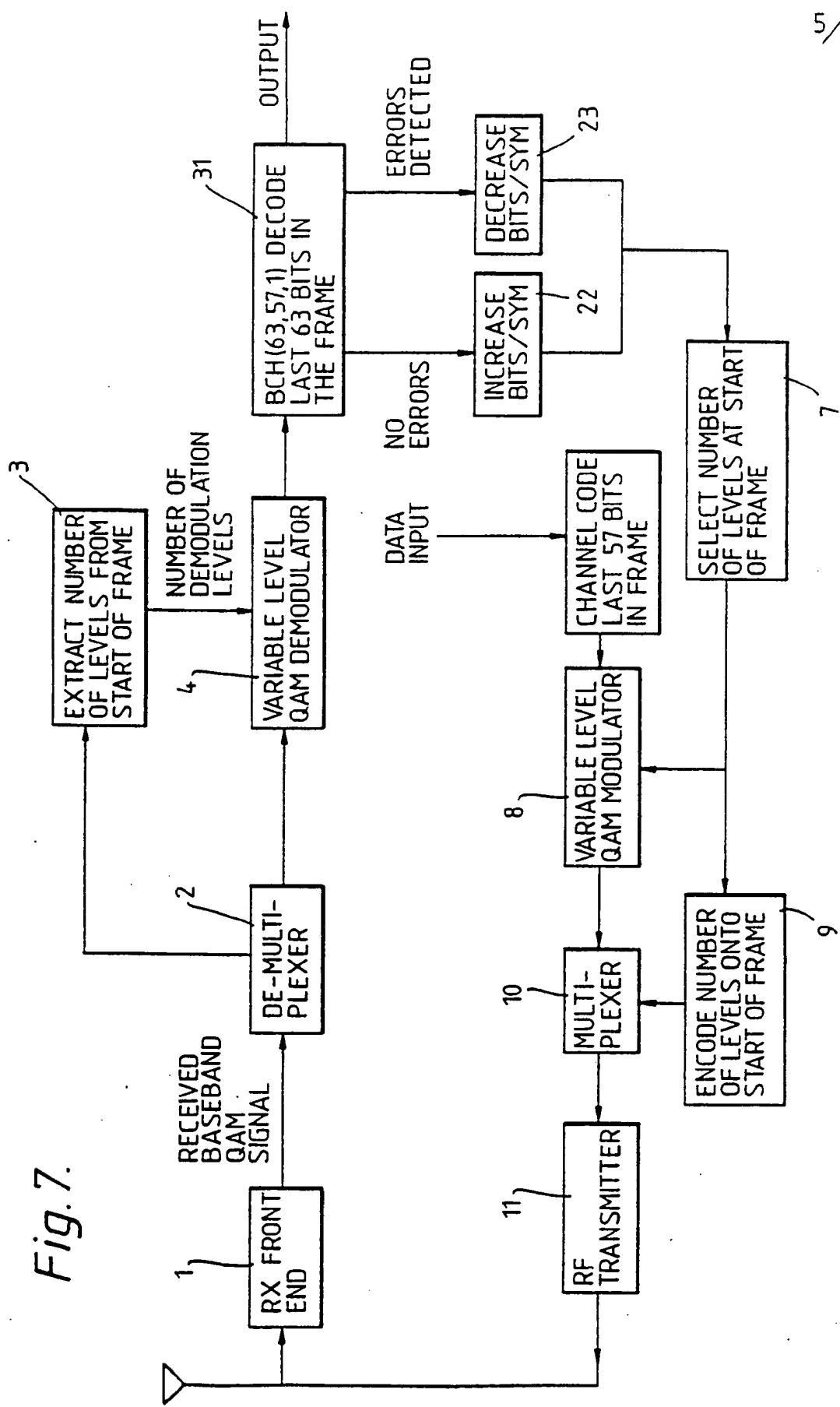
Fig.8.

EXAMPLE OF BER SWITCHING
BER SWITCHING SYSTEM
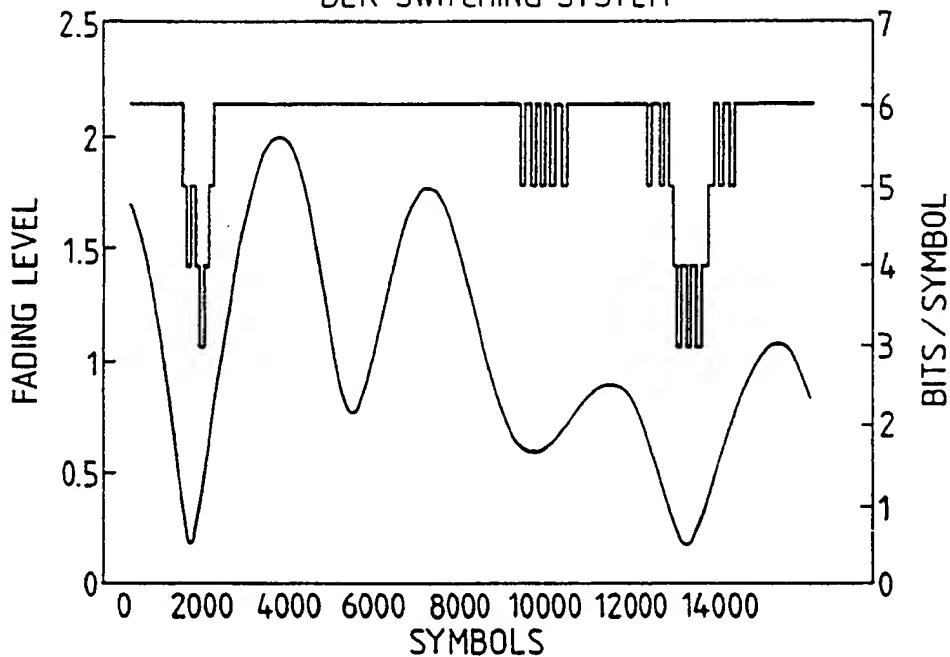
Fig.9.

PERFORMANCE IN A DECT-LIKE SYSTEM